Optical System for Providing a Useful Light Beam Influenced by Polarization

[001]   The following disclosure is based on German Patent Application No. 102 58 732.9 filed on December 6, 2002, which is incorporated into this application by reference.

BACKGROUND OF THE INVENTION

Field of the invention

[002]   The invention relates to an optical system for providing a useful light beam influenced by polarization. The invention relates, more particularly, to optical systems which provide a useful light beam for wafer exposure in microlithographic projection exposure machines.

Description of the Related Art

[003]   In the named specific application of wafer exposure, one or more deflecting mirrors are frequently used in the optical system, which is typically composed of an illuminating system upstream of the reticle plane or mask plane, and a projection objective between the reticle plane and wafer plane. As is known, p-polarized light, that is to say light polarized linearly parallel to the plane of incidence, is attenuated more strongly in the case of reflection at a deflecting mirror than is s-polarized light, that is to say light polarized linearly perpendicular to the plane of incidence. On the other hand, it is desirable in conjunction with

high requirements placed on the imaging quality that the p-component and the s-component of the illuminating light are as equal as possible in the wafer plane.

[004]   This problem is addressed, for example, in the Laid-Open Patent Application DE 198 51 749 A1 for the case of a catadioptric objective with a plurality of deflecting mirrors, the latter also to be understood in the present case as appropriate deflecting prisms. It is proposed there as a remedy to arrange the deflecting mirrors in a compensated fashion independently of polarization, specifically with planes of incidence which are not parallel, and, in particular, perpendicular to one another. This remedial measure is, however, suitable only for systems having a plurality of deflecting mirrors, and the design of the illuminating system and projection objective in the overall optical system does not always permit such an arrangement of deflecting mirrors with non-parallel planes of incidence. The measure proposed there as an alternative, of providing the at least one deflecting mirror of an objective with a thin, polarization-specific layer, in particular a phase-correcting dielectric layer, can be implemented only with difficulty for applications with large beam divergences and short wavelengths.

[005]   US Patent 5,475,491 discloses an exposure system in which a fraction of the light generated by a laser, for example, is coupled out to a photodetector at a semi-transmitting mirror by means of reflection, while the light fraction transmitted by the semi-transmitting mirror forms the useful light beam for exposure. The exact exposure dose is to be detected by the detector. Since, however, the respective degree of reflection and

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transmission of the semi-transmitting mirror differs for the s-polarized component and the p-polarized component, the detector result cannot be used directly to infer the true exposure dose when the polarization state of the incoming light is not known or varies upstream of the deflecting mirror. As a remedy, a plane transmission plate is introduced obliquely relative to the optical axis with an adjustable angle of inclination into the beam path of the coupled-out detection light between the deflecting mirror and detector. This angle of inclination is then set, as a function of the degree of transmission and reflection of the semi-transmitting mirror, for s- or p-polarized light such that the light intensity arriving at the detector is always proportional, independently of the possibly varying s-polarized or p-polarized light fractions, to the intensity of the useful light transmitted by the semi-transmitting mirror. The relative fractions for the s- and p- components of the useful light are not fixed thereby and can vary as desired depending on the design of the system part upstream of the semi-transmitting mirror.

SUMMARY OF THE INVENTION

[006]   The invention is based on the technical problem of providing an optical system of the type mentioned at the beginning which is capable of making available a useful light beam having light fractions that are the same or in any case differ comparatively little, of two different linear polarization states even when the light supplied by an associated light source already has a marked imbalance of these light fractions, or

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such an imbalance is caused by one or more other system components, such as, for example, deflecting mirrors.

[007]   According to one formulation of the invention, this problem is solved by providing an optical system including a compensation unit having at least one transmission plate which is inclined to the optical axis and is introduced into the light beam path. The effect of the oblique position is that the plate at-tenuates the light fraction with a first linear polari-zation state, for example, s-polarized light, more strongly in transmission than the light fraction with a second linear polarization state differing therefrom, for example, p-polarized light. This is utilized ac-cording to the invention for the purpose of completely or in any case partially compensating an imbalance of the two useful light fractions which is caused by the system without the compensation unit, for example, by deflecting mirrors.

[008]   In a development of the invention the transmission plate includes a transparent plate which is provided with a transmitting coating. With the aid of a suitably selected coating, the effect that the useful light fraction with the first linear polarization state is attenuated to an extent dependent on the light inci-dence angle more strongly than the useful light frac-tion with the second linear polarization state can be achieved or amplified in a desired way.

[009]   In a further development of the invention the system has one or more deflecting mirrors which cause the imbalance of the two useful light fractions. The inclination angle and/or the coating of the transmis-

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sion plate are selected as a function of the magnitude of this imbalance, preferably for the purpose of complete compensation. Further, a measuring device for determining the polarization degree can be provided in the beam path downstream of the deflecting mirror or mirrors and can be used to measure the imbalance of the two useful light fractions, in order suitably to control the inclination angle or the coating as a function of the measurement result, if required even also subsequently after a specific pre-setting has previously been selected. A further refinement of this measure is based on an imaging system, as an optical system, in which the transmission plate and a deflecting mirror are arranged at least approximately in planes of the imaging system which are conjugate to one another. Consequently, light incidence conditions similar to one another, in particular, incidence angle distributions, are present for the transmission plate, on the one hand, and the deflecting mirror, on the other hand, and this facilitates a possibly spatially dependent polarization compensation.

[010]   Given a non-constant incidence angle distribution of the useful light incident on a deflecting mirror of the system, the result is a correspondingly spatially dependent imbalance of the two useful light fractions with a different linear polarization state. A refinement of the invention also permits for this case a substantially complete compensation of this imbalance by virtue of the fact that the coating is correspondingly applied to the transparent plate in a spatially dependent variable manner.

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[011]   Another development of the invention is likewise
based on an imaging system as the optical system. In
this case, the compensation unit has a second transmis-
sion plate which is introduced into the useful light
beam path in an oblique fashion relative to the optical
axis, with an inclination angle which is opposite to
that of the other transmission plate. It is possible
thereby to compensate, completely or partially, asym-
metric aberrations which are caused by the oblique in-
troduction of one transmission plate into the imaging
system. For the purpose of a substantially complete
compensation, it is expedient for both transmission
plates to be of the same dimensions and to be arranged
with opposite inclination angles of the same size.

BRIEF DESCRIPTION OF THE DRAWINGS

[012]   Advantageous embodiments of the invention are
illustrated in the drawings and described below. In the
drawings:

Figure 1   shows a diagrammatic side view of a part of
           an optical system for a microlithographic
           projection exposure apparatus,

Figure 2   shows a longitudinal sectional view of an ob-
           jective for an illuminating system of a mi-
           crolithographic projection exposure appara-
           tus,

Figure 3   shows a characteristic diagram of reflectance
           as a function of incidence angle for a de-
           flecting mirror used in the objective of Fig-
           ure 2,

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Figure 4   shows a characteristic diagram of transmit-
           tance as a function of incidence angle for a
           first implementation of a transmission plate
           inserted into the objective of Figure 2,

Figure 5   shows a characteristic diagram corresponding
           to Figure 4 but for a second implementation
           of the transmission plate, and

Figure 6   shows a longitudinal sectional view of an-
           other objective for an illuminating system of
           a microlithographic projection exposure appa-
           ratus.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[013]   Figure 1 illustrates diagrammatically the problem
of the different attenuation of s-polarized light and
p-polarized light by deflecting mirrors, and the elimi-
nation of the imbalance, caused thereby, of the inten-
sity of s- and p-polarized components, with reference
to the example of an optical imaging system for a mi-
crolithographic projection exposure apparatus. Such an
imaging system is known to consist of an illuminating
system upstream of a reticle/mask plane 1, for the pur-
pose of providing light for trans-luminating a mask in-
serted there, and of a projection objective between the
reticle plane 1 and wafer plane 2 for the purpose of
projecting the mask structure onto a wafer inserted
into the wafer plane 2. Deflecting mirrors are present,
e.g. for the purpose of achieving a compact system de-
sign, in the illuminating system and/or in the projec-
tion objective, depending on system design.

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[014]   A first deflecting mirror 3 is provided in the
illuminating system, and two deflecting mirrors 4, 5
are provided, as 45° deflecting mirrors in each case,
in the projection objective in the example of Figure 1.
The two deflecting mirrors 4, 5 serve the purpose in
the projection objective of, for example, implementing
a catadioptric design, indicated diagrammatically by a
reflecting mirror 6. The remaining system components
such as lenses, etc. are omitted in Figure 1 for the
sake of clarity, since they play no role with regard to
the different attenuation of s- and p-polarized light.

[015]   The three deflecting mirrors 3, 4, 5 are arranged
such that the normals to their planes all lie in one
plane, the plane of the drawing of Figure 1. Also lying
in this plane is the optical axis of the system, repre-
sented by a main light beam 7 which is shown represen-
tatively for the entire light beam bundle. This plane
therefore forms a common incidence plane for all three
deflecting mirrors, 3, 4, 5. The relative amplitudes or
intensity fractions of s-polarized light, that is to
say light polarized perpendicular to the incidence
plane, and of light polarized perpendicular thereto,
that is to say p-polarized light, are illustrated, as
is customary, by the length of an arrow belonging to
p-polarized light, and the diameter of a double circle
belonging to s-polarized light.

[016]   As may be seen from Figure 1, it can be assumed
without restricting generality that the light on the
output side of a diaphragm 8 of the illuminating system
has fractions of s- and p-polarized light of the same
size. Moreover, it may be seen from a comparison of in-

cident and reflected light that each deflecting mirror
3, 4, 5 deflects the p-polarized light fraction with a
distinctly stronger attenuation by comparison with the
s-polarized light fraction (shortening of the associ-
ated p arrows accompanied by a substantially constant
diameter of the s circles in Figure 1). Consequently,
without further measures, the useful light provided on
the wafer plane 2 would contain a p-polarized light
fraction distinctly reduced by comparison with the
s-polarized fraction.

[017]   In order to avoid this imbalance of s- and
p-polarized light fractions, there is introduced into
the beam path of the useful light 7 a compensation ele-
ment in the form of a transmission plate 9 which is
preferably implemented as a plane plate coated at least
on one side. The transmission plate 9 is likewise ar-
ranged with the normal to the plane lying in the inci-
dence plane, it being inclined with its plane by a pre-
scribable angle of inclination β with reference to the
plane perpendicular to the optical axis. In other
words, the transmission plate 9 is tilted with refer-
ence to this plane about the axis parallel to the di-
rection of s-polarization. This arrangement of the
transmission plate 9 obliquely relative to the optical
axis 7 has the consequence that the s-polarized frac-
tion of the light passing through it is markedly at-
tenuated, while the p-polarized light fraction passes
through in a substantially less attenuated fashion.

[018]   The material and the dimensioning of the transmis-
sion plate 9 and, specifically, of the coating, par-
ticularly as regards their refractive index and their
thickness, and the angle of inclination β are selected

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as a function of the magnitude of the imbalance, exist-
ing without the transmission plate 9, of s- and
p-polarized light such that the degree of relative at-
tenuation of the s-polarized light by the transmission
plate 9 corresponds entirely or in any case largely to
the extent of relative attenuation of the p-polarized
light by the deflecting mirrors 3, 4, 5. Correspond-
ingly, the imbalance, caused by the deflecting mirrors
3, 4, 5, of s- and p-polarized light is completely or
in any case partially compensated by the transmission
plate 9. Overcompensation is also possible if required.
The imbalance can be detected, for example, by means of
a conventional measuring device for determining the de-
gree of polarization, which is arranged downstream of
the last deflecting mirror 5 in the beam path. The an-
gle of inclination β and/or the coating are then set in
a desired way depending on the measurement result, and
readjusted if required.

[019]   Correspondingly, the optical system equipped with
the transmission plate 9 makes available a useful light
beam, here for the purpose of wafer exposure, whose
s-polarized light fraction can be set to a desired ex-
tent relative to the p-polarized light fraction,
whereby attenuation of the p-polarized light fraction
which is caused by deflecting mirrors or other system
components is exactly compensated, under or over com-
pensated depending on application. The compensation ef-
fect of the transmission plate 9 can be influenced spe-
cifically, during its fabrication, by the selection of
material and by the type and thickness of a coating
which is optionally applied, this, if required, being
performed variably depending on location. During use of
the transmission plate 9, the compensation effect can

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be set to a respectively desired value by the selection
of an appropriate angle of inclination β.

[020]   Figure 2 shows an exemplary embodiment, imple-
mented in practice, in the form of an objective 10
which is used in an illuminating system in accordance
with Figure 1 and is also denoted as an ReMa objective,
and includes the first deflecting mirror 3 of Figure 1,
on the illuminating system side, and the transmission
plate 9. With the exception of the additional transmis-
sion plate 9, this objective has a conventional design
consisting of diverse, diagrammatically reproduced op-
tics components, in particular lenses and diaphragms,
as well as the deflecting mirror 3, the optical action
of which components is rendered clear with the aid of
the illustrated beam paths, and which do not require
any kind of more detailed explanation here. The trans-
mission plate 9 and the deflecting mirror 3 are pref-
erably arranged approximately at the level of conjugate
planes of the objective 10. This results in similar in-
cidence angle distributions for the transmission plate
9 and the deflecting mirror 3, such that a coating
which is spatially uniform over the entire translumi-
nated surface of the transmission plate 9, suffices to
achieve a uniform, preferably complete compensation of
the imbalance of s- and p-polarized light fractions at
all field points of the overall field region of the ob-
jective 10.

[021]   When the incidence angle distributions are not so
similar that it is possible to achieve the desired com-
pensation at all field points with the aid of a uniform
plane plate coating, it is alternatively possible to
provide a spatially variable coating for the transmis-
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sion plate 9, doing so in such a way that the local variation of the coating at each field point corresponds to the variation of the incidence angle distribution, that is to say for each field point, the transmission plate 9 compensates the location-dependent attenuation, caused by the deflecting mirror 3, of the p-polarized light fraction by means of a location-dependent attenuation, preferably of the same magnitude, of the s-polarized light fraction. A similar statement holds for the case in which the transmission plate 9 has to compensate the attenuation effect of a plurality of deflecting mirrors, as in the example of Figure 1. Alternatively, each deflecting mirror can respectively be assigned a transmission plate introduced obliquely.

[022]   The quantitative determination of the parameters of the transmission plate 9, in particular as regards the coating and the angle of inclination β, in relation to the compensation, explained above, of the imbalance, caused by the deflecting mirror 3, of s- and p-polarization fractions in the useful light beam path is explained below with reference to Figures 3 to 5.

[023]   Figure 3 shows the typical variation of the characteristics of the reflectance of a deflecting mirror such as the deflecting mirror 3 of Figures 1 and 2, as a function of the incidence angle for p-polarized light (continuous characteristic curve), on the one hand, and s-polarized light (dashed characteristic curve), on the other hand. A typical operating range A_U for a 45° deflecting mirror is given between the dotted boundaries. In this example, the incidence angles are distributed between approximately 36° and 54° about the

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mean value of 45°. As may be seen from Figure 3, the difference between the reflectance for s-polarized light and that for p-polarized light rises continuously with the increasing incidence angle, and thus also does the difference in the polarization attenuation of p-polarized light relative to s-polarized light. Over the operating range A_U, this difference in the reflectance and thus in the polarization attenuation increases from a minimum value Δ_{Uu} up to maximum value Δ_{Uo} with a mean value of Δ_U for the mean incidence angle of 45°.

[024]   Figure 4 shows transmittance as a function of incidence angle for an implementation of the transmission plate 9 as a plane plate which is provided with a coating which has a thickness of 30 nm and a refractive index of 1.45, specifically, in turn, for p-polarized light (continuous characteristic curve), on the one hand, and s-polarized light (dashed characteristic curve), on the other hand. As may be seen therefrom, the transmittance decreases continuously for s-polarized light in the range considered, while for p-polarized light it even slightly increases at first, that is to say the transmission plate 9 attenuates the s-polarized light fraction ever more strongly relative to the p-polarized light fraction with an increasing incidence angle in the incidence angle range considered.

[025]   It is therefore always possible to find an operating range A_{T1}, indicated in Figure 4 by dotted boundaries, for the transmission plate 9, which leads to as complete a compensation as possible of the polarization imbalance, caused by the deflecting mirror

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3, for the incidence angles occurring here. Firstly,
the angle of inclination β is determined for this pur-
pose such that the difference Δ_{T1} resulting for it in
the transmittance of the transmission plate 9, and thus
in its attenuation of the polarization of p- and
s-polarized light corresponds to the difference Δ_U in
the reflectance of the deflecting mirror 3, and thus,
in the polarization attenuation thereof of s- and
p-polarized light given a selected tilting angle of
45°, which is the mean incidence angle. The transmis-
sion plate 9 is introduced into the useful light beam
path with this angle of inclination β of approximately
30°, in this case.

[026]   When the transmission plate 9 and deflecting
mirror 3 lie in conjugate planes of the objective of
Figure 2, the transmission plate operating range A_{T1}
about the angle of inclination β corresponds to the de-
flecting mirror operating range A_U, this operating range
A_{T1} ranging from approximately 24° to approximately 36°
in the example of Figure 4 shown. The minimum differ-
ence Δ_{T1u} and maximum difference Δ_{T1o}, resulting for this
operating range A_{T1}, in the polarization attenuation
through the transmission plate 9 then likewise corre-
sponds in absolute value to a very large extent to the
relative minimum attenuation value Δ_{Uu} or the maximum
attenuation value Δ_{Uo} of the deflecting mirror 3. This
makes it plain that here a uniform coating of the
transmission plate 9 suffices for a compensation, uni-
form over the entire relevant image field of the objec-
tive, of the different attenuation of s- and
p-polarized light owing to the deflecting mirror 3.
This holds specifically when the incidence angles at

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the various points of the deflecting mirror 3 are largely equal, so that then the difference in polarization attenuation, induced by the deflecting mirror 3, for s-polarized light or p-polarized light is approximately constant in the relevant plane.

[027]   In the event of variations in the incidence angle distribution and/or in the event of a deviation of the position of the transmission plate 9 from a plane conjugate to the deflecting mirror or mirrors 3, a compensation being to a very large extent uniform and complete over the entire image field can be achieved by virtue of the fact that the coating is applied to the plane plate in a correspondingly different, spatially variable fashion, in particular as regards its thickness and/or its material.

[028]   Figure 5 illustrates the dependence of the transmittance on the incidence angle for a second implementation of the transmission plate 9 in the form of a plane plate with a coating which has a thickness of 30 nm and a refractive index of 1.65, once again for p-polarized light (continuous characteristic curve), on the one hand, and for s-polarized light (dashed characteristic curve), on the other hand. Qualitatively, the forms of the characteristic curves correspond to those of Figure 4, but the difference between p- and s-polarized light is less for the same incidence angle. Consequently, the result in this case is a larger angle of inclination β of approximately 47°, for which the relative attenuation difference Δ_{T2} corresponds in terms of absolute magnitude to the mean polarization attenuation difference Δ_U of the deflecting mirror 3. In this

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case, a transmission plate operating range A_{T2} from approximately 40° to approximately 54° corresponds to the deflecting mirror operating range A_U. Once again, the minimum polarization attenuation difference Δ_{T2u} and the maximum polarization attenuation difference Δ_{T2o}, resulting therefrom, as they are given by this transmission plate operating range A_{T2} correspond to a very large extent in absolute value to, respectively, the minimum and maximum polarization attenuation difference Δ_{Uu}, Δ_{Uo} of the deflecting mirror 3.

[029]   The introduction of the tilted transmission plate 9 into an imaging system such as the imaging objective of Figure 2 can produce aberrations which are not rotationally symmetrical in relation to the optical axis, and can therefore not be compensated straight away by the lens elements of the system. If the transmission plate is relatively thin, these aberrations may be negligible. In order to compensate the asymmetric aberrations in the case, in particular, when use is made of a transmission plate of marked thickness, it is possible to introduce into the useful light beam path a further transmission plate of the same dimension which, by comparison with the plane perpendicular to the optical axis, is inclined about the same axis, but in a fashion opposite to the other, first transmission plate. Both plates are preferably separated only by an air gap. It is preferred, but not mandatory for the two angles of inclination to be selected with the same absolute magnitude.

[030]   Such an implementation is given in Figure 6 for the case of the objective of Figure 2. In addition to

the setup of Figure 2, a second transmission plate 11 is arranged in a fashion tilted in the useful beam path in relation to the plane perpendicular to the optical axis and behind the transmission plate 9, which is arranged with the angle of inclination β, the said second transmission plate being of the same dimension as the first and having an opposite angle of inclination β of the same size. It is preferred in this case to select the transmission plate coating such that moderately large angles of inclination β suffice to enable the two transmission plates 9, 11 to be positioned without impediment one behind the other in the otherwise unchanged objective 10'. In this exemplary embodiment, the two transmission plates 9, 11, which are preferably similarly coated, can contribute to the compensation effect with regard to polarization attenuation.

[031]   As the above-described exemplary embodiments make plain, the invention makes available an optical system which supplies a useful light beam which, despite the presence of one or more deflecting mirrors or other optical components which attenuate two different linear polarization states differently, supplies at the output end a useful light beam in which the light fractions of the two linear polarization states bear a desired relationship to one another, preferably being essentially of the same size. Provided for this purpose is a compensation unit having at least one transmission plate which is introduced obliquely into the beam path and completely or partially compensates this behaviour of the remaining part of the optical system.

[032]   The intensity ratio of the useful light fractions
of the two linear polarization states can be set to a
desired value by selecting the material and the angle
of inclination of the transmission plate and by using
an optimum coating. The transmission plate is prefera-
bly inclined about an axis parallel to the tilting axis
of the respective deflecting mirror. It is still possi-
ble during operation to carry out fine setting of the
compensation effect by appropriate variation of the an-
gle of inclination. During use in imaging systems, it
is advantageous to position the transmission plate in a
plane conjugate to the plane of a deflecting mirror.
Different incidence angle distributions for the respec-
tive deflecting mirror, on the one hand, and the trans-
mission plate, on the other hand, can, if required, be
compensated completely or partially by a coating which
is variable over the irradiated plate surface as a
function of location. During use in imaging systems,
possible asymmetric aberrations caused by the transmis-
sion plate can be compensated by arranging a similar
second transmission plate with an opposite angle of in-
clination of the same size.

[033]   It is possible to achieve in this way, for
objectives with a deflecting mirror such as are used in
an illuminating system and as a projection objective in
microlithographic exposure apparatuses, that there is
available in the mask plane and, in particular, in the
wafer plane light whose s-polarized component and
p-polarized component are present at substantially the
same intensity. In particular, with the aid of this
measure it is also possible to achieve compensation for
systems with an odd number of deflecting mirrors, and
for systems in which a plurality of deflecting mirrors

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with a common incidence plane, that is to say parallel tilting axes, are arranged. It goes without saying that the invention can be used not only for microlithographic projection exposure apparatuses, but also for any other optical systems which provide a useful light beam by using one or more optical components which attenuate two different linear polarization states of the useful light beam in a different way.

[034]   The above description of the preferred embodiments has been given by way of example. From the disclosure given, those skilled in the art will not only understand the present invention and its attendant advantages, but will also find apparent various changes and modifications to the structures and methods disclosed. It is sought, therefore, to cover all changes and modifications as fall within the spirit and scope of the invention, as defined by the appended claims, and equivalents thereof.